Measuring single-particle absorption from elastic light scattering patterns of complex aggregates

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Introduction

Is there a way to determine absorbance of a single aerosol particle from its light scattering?

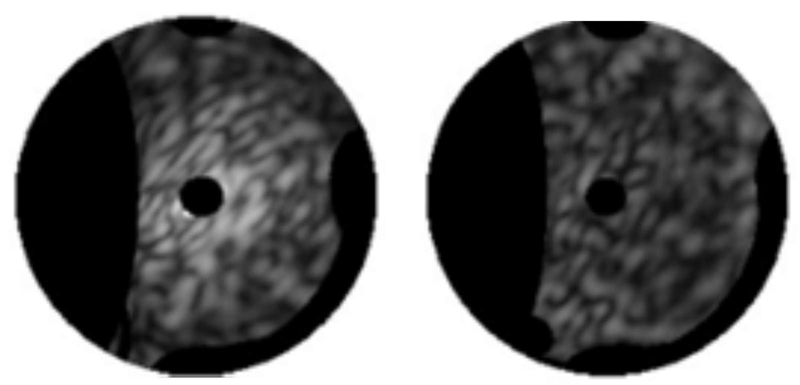

Figure 1. Forward (left) and backward (right) scattering patterns of an aerosol particle from a database of over 30,000 scattering patterns (TAOS patterns) provided by the US Army Research Laboratory.

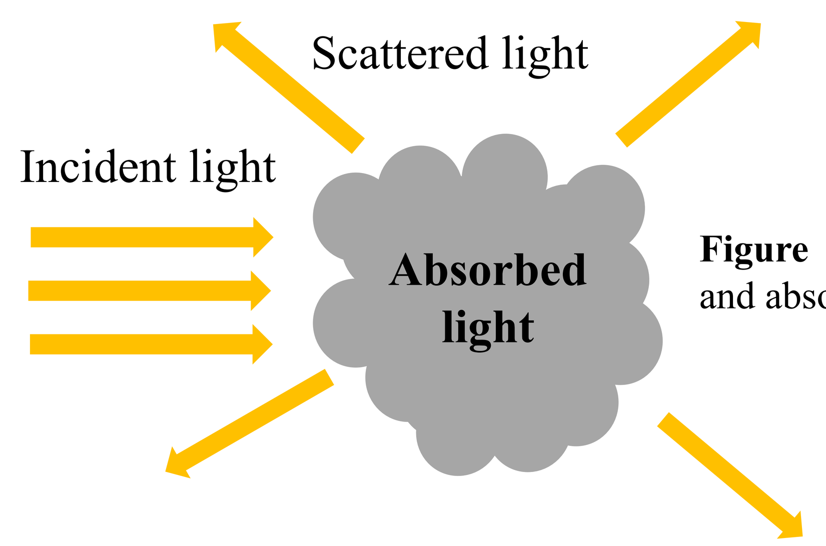

Figure 2. An aerosol particle scatters and absorbs incident light.

Particle absorbance is one possible pathway to discriminate between different types of particles. We explore a potential method for characterizing the absorption of a single particle by analyzing the two-dimensional angularly-resolved optical scattering (TAOS) pattern of the particle. For a complex aggregate, the light scattering cross-section of a particle is strongly dependent on the overall size as well as the absorptive properties of the particle. By performing an auto-correlation analysis of the TAOS pattern, we can estimate the size of the aggregate independent of its absorption. We can also measure, within the constraints of our experimental geometry, the approximate light scattering intensity from the scattering pattern. With the scattering intensity and nominal particle size we can roughly estimate the absorption of the particle. This approach was tested by simulating the scattering from a cluster of spheres using multi-sphere T-matrix method code.

Simulation

To simulate an aerosol particle, MATLAB code creates the position of constituent spheres in a sphere cluster. Using this method, particle size, constituent sphere size, absorbance and real refractive index can be parameterized. The position file is then sent to a MSTM (Multi-Sphere T Matrix) code created by Dan Mackowski which creates a scattering intensity file. This intensity file can be used to create a simulated scattering pattern of the particle. Particles types listed in Figure 4 were simulated from size 1 to 10 µm.

Type	Real Refractive Index	Imaginary Refractive Index
Oceanic	1.38	4.3×10^{-9}
Dust	1.53	8×10^{-3}
Sulfate	1.53	7×10^{-3}
Soot	1.75	0.43

Figure 4. The refractive properties of oceanic, dust, sulfate and soot particles were used to simulate sphere clusters.

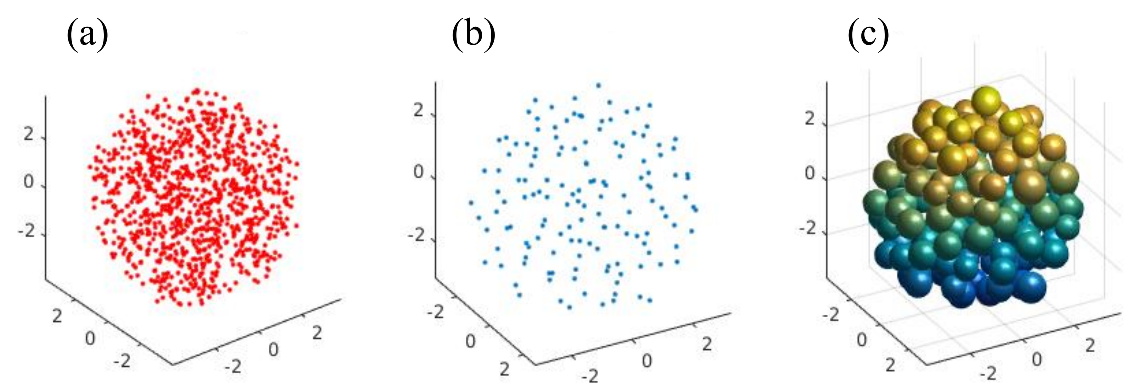

Figure 3. A Matlab code is used to (a) create many random small spheres within a certain radius, (b) remove any spheres that overlap with each other, and (c) expand each constituent sphere until it touches another or reaches the radial limit of the particle.

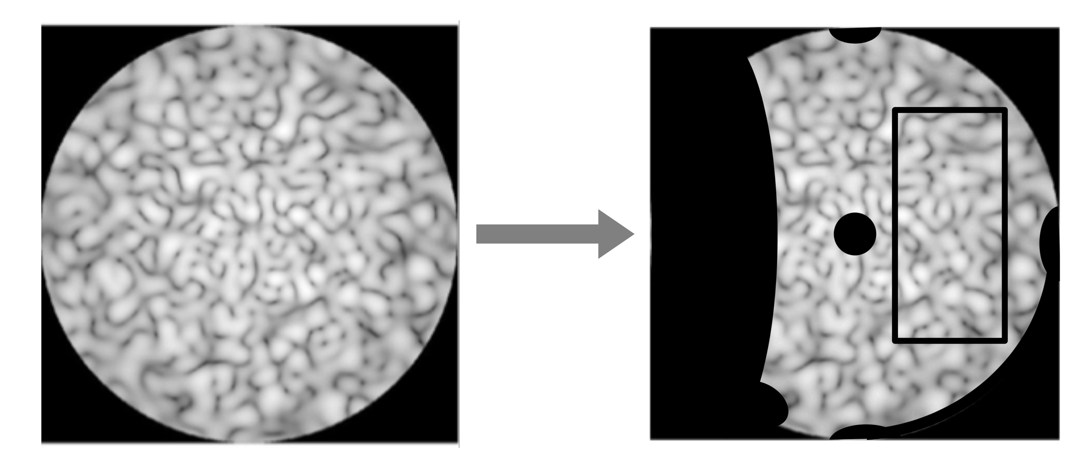

Figure 5. The restrictions of the experimental geometry is mapped onto a simulated backward scattering pattern. A rectangular section of the scattering pattern is selected for autocorrelation.

Result

We can determine the speckle size of a scattering pattern using an autocorrelation method for a section of the pattern indicated in Figure 5. The speckle size is inversely proportional to the overall size of the particle, shown in Figure 7. As such, we are able to estimate particle size solely from a scattering pattern. With the auto-correlated diameter and the integrated scattering intensity (i.e. the total intensity after accounting for experimental geometry) we are able to gain insight into particle absorption, independent of any previous knowledge of properties of the particle. From our new absorption characterization method, we can show that the particles with higher scattering intensity are less absorptive than particles with lower scattering intensities of the same size, as seen by Figure 8. Over 30,000 experimentally determined TAOS patterns from atmospheric aerosols were analyzed using this technique. Results are shown in Figure 9. Based on our simulation analysis, we are now able to estimate which particles, of a particular diameter, have higher or lower absorption.

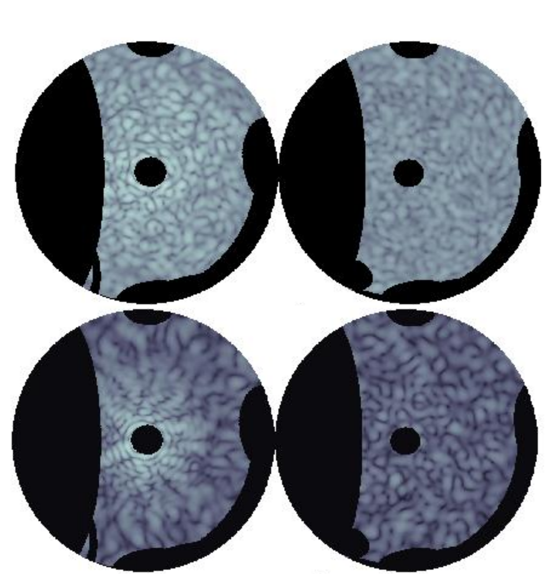

Figure 6. Oceanic (top) and soot (bottom) aerosol scattering patterns of particles with identical shape and size are scaled to the same brightness to show visibly different scattering intensities.

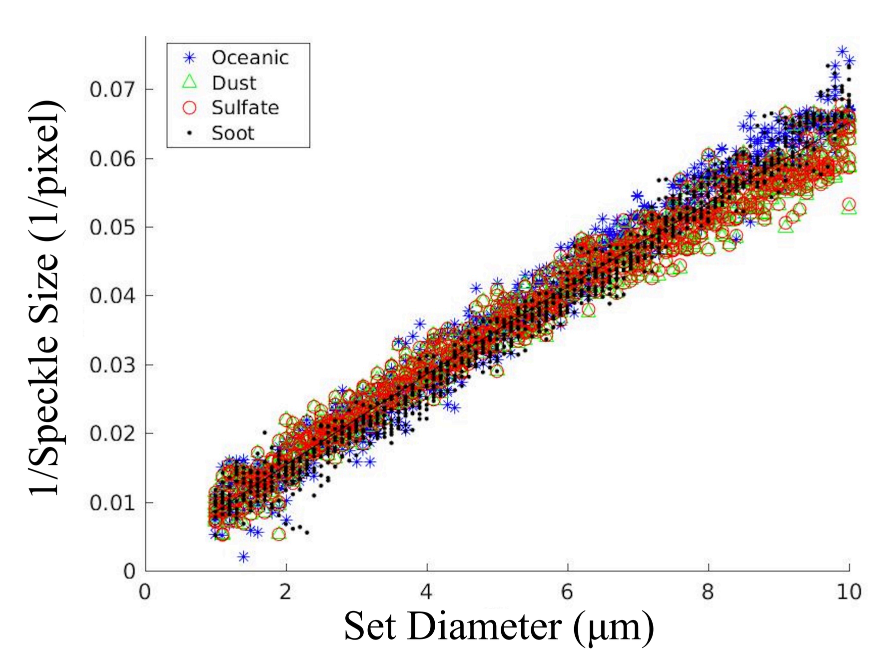

Figure 7. Speckle size has an inverse relationship to the parameterized diameter of the simulated particle. Speckle size is the average size of the little pockets of brightness in a scattering pattern.

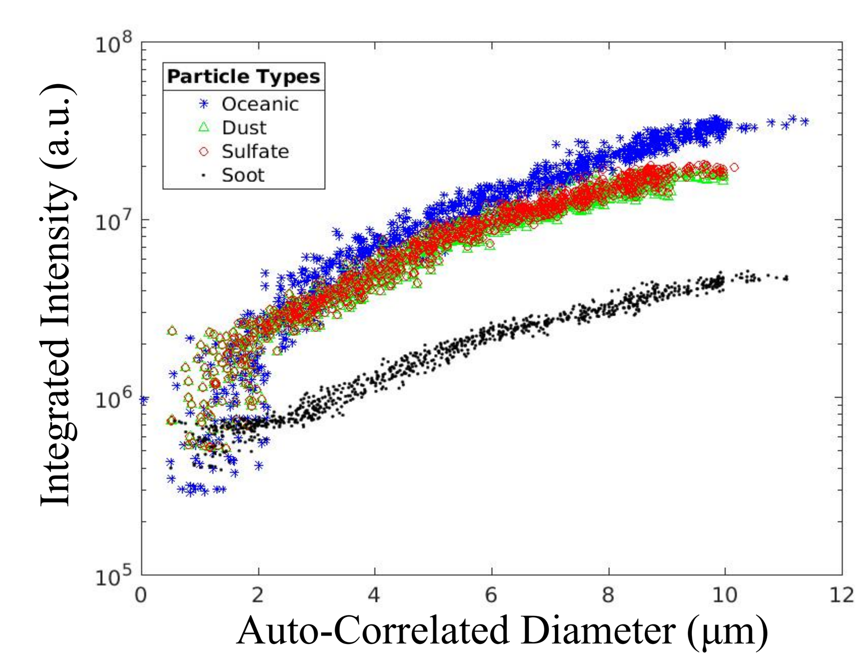

Figure 8. Particles with low absorption have a higher scattering intensity than particles with high absorption of the same size. For example, soot—a highly absorptive particle—has the lowest intensity values. Note the diameter estimation becomes unreliable for small particles.

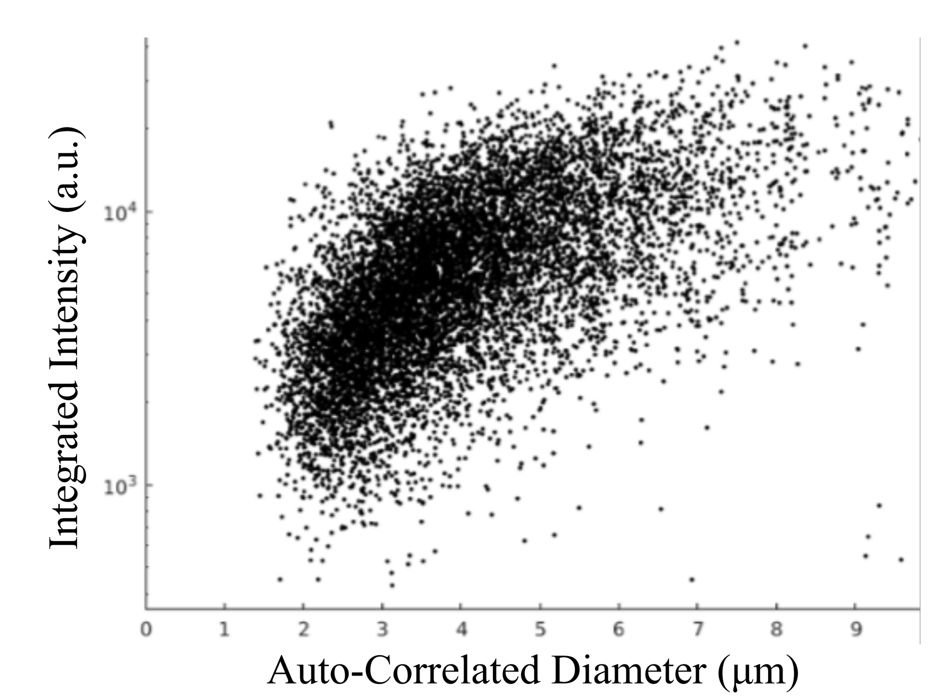

Figure 9. The 30,000 TAOS patterns create a cloud of data points when comparing scattering intensity and size. For a fixed size, particles with higher intensity most likely have less absorption.

Conclusion

We have shown a possible pathway for estimating single-particle absorption from light scattering. Our technique utilizes the speckle in TAOS patterns to estimate particle size. Once particle size is known, the total scattering intensity can be used to estimate particle absorption. Analysis was performed on TAOS patterns captured from atmospheric aerosols. The next step would be to conduct a more controlled experiment with particles of known composition.

Acknowledgements

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